Failure Analysis, Part II—Case Histories

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The academic side of failure analysis was presented in Part I of this article (December 2007 MP). This included 1) steps in conducting a failure analysis, 2) typical tools, and 3) theory of crack propagation.

This article provides several case studies demonstrating the use of these techniques.

Engineers want to conduct an analysis to determine the root cause of component failure. Manufacturing companies want to save money by minimizing unscheduled outages. Insurance companies want to know if the failed component was abused and thus leads to a claim. Attorneys need engineering data for demonstrative evidence.

Part I of this article discussed the use of typical tools that included:

- Visual exam.
- Macroscopic and microscopic exam.
- The use of scanning electron microscopy (SEM).

The steps in conducting a failure analysis are:

- Preserve the components.
- Gather background information.
- Perform nondestructive analysis.
- Conduct chemistry analysis.
- Brainstorm possible failure mechanisms.
- Perform stress analysis.
- Perform mechanical testing.

This article uses the above concepts in a few case studies showing how engineering knowledge and the ability to apply it solves failure analysis problems.

Mausoleum Bolt—Stress Corrosion Cracking

Fracture surfaces contain many features that help the failure analyst determine the root cause of failure. Inscripted marble slabs were falling off the front of a mausoleum. Some of the slabs were 20 ft (6 m) in the air; fortunately no one was injured. The slabs were held in place with brass bolts that did not have any loads from the marble slab; the entire weight was supported by other hardware. The brass bolts merely kept the marble slabs vertical, yet it was these bolts that were failing. Figures 1 through 3 depict the failed bolts. Results of the examination showed that
stress corrosion cracking (SCC) had occurred, as shown in Figures 2 and 3. The bolts were exposed to ammonium via fertilizer; ammonium can cause SCC in brass. The source of stress was puzzling. Visiting the site and watching the removal of bolts that would be analyzed revealed the high levels of torque used during the installation. Residual stress was also present because of the cold heading operation, which was not followed by annealing. Details of this failure can be found elsewhere. If one of the three criteria for SCC had been removed—1) presence of stress, 2) corrosive environment, and 3) susceptible material—then these failures could have been prevented.

**Vehicle Fire—Melting Temperature vs Location**

A recreational vehicle (RV) caught fire while parked in a camping area. Two people were injured and one later died. The fire was suspected to have originated at the liquefied petroleum gas line that passed through the passenger side front wheel well. It was opined that constant impact from road debris propelled from the tire penetrated the gas line tube; the leak then ignited.

The approach in this case was to use metallurgical knowledge of phase diagrams and melting temperatures to show the temperatures experienced in various locations throughout the RV. By examining the surface of various metals (steel, copper, and aluminum) located in the engine compartment, the temperatures could be bracketed. Melting of aluminum (1,220°F [660°C]) caused the molten aluminum to drip onto copper tubing. Copper melts at 1,985°F (1,085°C), whereas eutectic melting of Cu + Al can occur as low as 1,018°F (548°C). Various components retrieved from the RV were
examined. Figure 4 shows the results of this analysis. The hottest part of the fire was located in the passenger front wheel well. Details of this case can be found elsewhere.9

**Weld Parameters—Heat-Affected Zone Cracking**

A manufacturing company was having difficulty with cracking in welds on stainless steel (SS) (ferritic SS with austenitic filler metal). The company submitted four samples with different weld parameters for metallurgical evaluation, consisting of microstructure and microhardness testing. Knowledge of microstructures is essential to understand the relationship among processing, alloy, performance, and structure.9 Figures 5 and 6 show several samples and results. Some of the recommendations were:

- Cool the weldments at a faster rate, perhaps by using a backplate to prevent sensitization and formation of martensite.
- Employ a cover gas for the top and bottom of the weld to minimize nitrogen pickup and the ensuing formation of martensite.
- Develop a consistent bend test to characterize the ductility of the welds.

**Conclusions**

- Preserving failed components for future evaluation is paramount in conducting a successful failure analysis.
- Developing hypotheses and using the proper tools validate or eliminate the possible failure mechanisms.
- Visual, microscopic, and SEM results along with chemistry and mechanical data allow the metallurgist to formulate a reasonable failure scenario.

![Temperature profile of engine area.](image1)

![Welded component; ductile weld (left) and brittle weld (right).](image2)

![Microstructure of fusion zone and base metal that exhibits grain growth and interface bonding (left) and poor interface quality and poor phase formation on the left half (right). Diamond shapes are microhardness indentations.](image3)
• The metallurgist can make recommendations regarding design, material selection, material processing, or presence of abuse to minimize future failures.

• Manufacturing companies can schedule preventive maintenance, insurance companies can pay valid claims, and lawyers can be justifiable.

References

5 M.R. Louthan, Jr., T.A. Place, eds., Microscopy, Fractography, and Failure Analysis, Failure Analysis and Prevention Lab (Blacksburg, VA: Virginia Polytechnic Institute, 1986).

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